

AL₃O₂ AND NICKEL COATINGS ON RESISTANCE WELDING ELECTRODES USING CHEMICAL VAPOUR DEPOSITION PROCESS TO EXTEND LIFE

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ABSTRACT

Any alteration in the standard machining process can lower the quality of finished product. This is especially true in high-speed machining operations, where despite the pace, the quality of the product and physical dimensions cannot be compromised. These alterations usually occur because of temperature influence, cutting force, and tool wear. Furthermore, temperature is a significant noise parameter. Temperature can directly impact the workings of the cutting tool and work piece. The purpose of this project is to study the machining effect on 6063 Aluminum alloy. The study was conducted at various combinations of work processes, and the parameters such as speed, feed rate and depth of cut were determined. In addition, the effect of these parameters on the quality of finished product was assessed. A L₂₇ orthogonal array (OA) based design of experiments (DOE) approach and response surface methodology (RSM) were applied in the study to investigate the machining effect on work material in this study. Using the practical data available, a mathematical model was proposed. This mathematical model was used to predict the temperature influence and surface quality of finished product. Eventually, the standardized machining parameters were adjusted and optimized. for the optimization ensured the reduction in temperature in machining zone and improvement in surface finish.

KEYWORDS: High-speed Machining, Cutting Force, Tool Wear & Work Piece

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INTRODUCTION

The usage of aluminium in the automobile industry, especially for manufacturing hoods and trunk lids, can reduce the weight of the product. At the same time, safety standards are ensured, with easy manufacturing. The automobile industry usually uses aluminum alloy sheets, which are processed and manufactured as automotive sheet steel. The alloy sheets can also be stamped and cut as steel. However, the drawback for its use is the problems that arise in its weld ability.

When aluminium was first introduced in the automotive industry, resistance spot welding was challenging and costly. This was mainly because aluminium was a lightweight and corrosion resistant material. The electrode had considerably short life, and while manufacturing at high production speeds, the weld quality could not be maintained. This was the main drawback that proved to be responsible for obstructing acceptance in comparison to other competitive materials.

Resistance welding is cumbersome in aluminium because of its thermal and electrical properties. It requires high current and short weld times to produce the optimal heat to weld nugget, as the heat is dissipated through the work sheet. Conventional, uncoated, domed-face electrodes weld aluminium sheet; however, these sheets have only short electrode lives. Copper and aluminium have stronger interaction than copper and zinc. Therefore, the degradation of copper alloy electrodes is more difficult when welding aluminium in comparison to

coated steels.

This study aims to determine the effects of Al_2O_3 /nickel coating on the electrode tip life were explored when welding aluminium alloy 5182. Various tip life trials were conducted. These experiments helped to determine the tip diameter and surface profile data. This study helped to understand performance, degradation and failure mechanisms of the coated electrode.

LITERATURE REVIEW

Thin film diamond coating by chemical vapor methods is an already accomplished process. Diamond is known to have a low coefficient of thermal expansion. Conducting the CVD growth process at high temperatures ensures that the substrate would have contracted more than the diamond film when cooling back to room temperatures. This causes compressive stress on the diamond film, and can be observed by the broadening and shifting of the 1332 cm Raman peak. The mismatch in the coefficients of thermal expansion for diamond and the substrate material will be the determining factor to analyze the possibilities to grow an adherent CVD diamond film on that particular substrate. The substrates usually are metals films. These metal films must have a texture and a degree of crystalline order intermediate between a typical polycrystalline CVD diamond film and a genuine single-crystal film. Diamond-coated fibers display better stiffness and strength in comparison to the non-coated fibers. This observation needs to be determined quantitatively by measuring the coated fiber properties. If growth rates can be elevated to economically viable standards, then diamond fibers have various applications. They may be used as reinforcing agents in metal-matrix composites; in addition, stronger, stiffer and lighter load-bearing structures can be manufactured that has wide applications in the aerospace industry [1].

[2] In the experiment, titanium and nitride were diffused for coating using conventional surface treatments or coatings. The method involves providing a base material with a coating, followed by a salt bath having sodium dioxide and a salt representative of the group consisting of sodium cyanate and potassium cyanate. Dispersing metallic titanium is formed by electrolysis of a titanium compound in the bath on heating the salt bath to 430°C , about a maximum of 670°C ; subsequently, the base material is soaked in the salt bath for about 10 minutes to about 24 hours. Alternatively, titanium and nitride may be diffused into a base material without a coating. The treated base material may be treated further using conventional surface treatments or coating. Titanium and nitrogen diffuse and fill the void within the coating structure as well as within base material structure. Moreover, the diffusion from the coating en route to the underlying base material results in the formation of a titanium interface or network.

[3] The deposition of TiSiB erosion resistance nano coating with MAX-phase on the surface of Ti6Al4V alloy parts by vacuum plasma method with plasma separation from drop fraction has been researched. These processes were dependent on the physical and chemical state of surface layers, as well as fatigue and erosion properties of samples and blades with these coatings. Initially, thin nano crystalline film coating made of various contents, such as titanium-silicon-boron-nitrogen system, of thickness with 3–4 μm layers and size of 2–5 nm (grain-sized) were formed. The last coating had very high values of hardness (more than 40 GPa) and low values of dry friction coefficient. The authors also developed a technological process of target production from exothermic blend of 55.2% Ti – 24.8% B – 20% Si (residual porosity was lesser than 5%). Coating precipitation was performed using an experimental electro-arch evaporator with arch magnetic field and universal source of quick neutral molecules beam combined with metal vapor flow dispersed by ions of target argon. High-frequency fatigue tests were conducted at 25°C in air (endurance limit of the samples without coating on basis of 2×10^7 cycles is equal to (250 ± 20) MPa). Erosion tests (duration of exposition T, kind

of particles – quartz sand of 80 micron in size, speed and angle of encounter are 200 m/s and 90 grades accordingly) of samples from BT6 alloy after coating of titanium-silicon-boron system were also conducted in the presence of MAX-phase in coating and low dispersion of material.

[4]The weld nugget is formed by the passing of current through the electrodes and the worksheets. The contact resistance at the interfaces produces heat. The bulk resistances in the work piece are determined by the equation $H=I^2Rt$, where H is the total heat, I the weld current, R the total circuit resistance, and t the weld time. The quality of the weld is based on the localized heat generation, or H/A , where A is the area of the contact face of the electrode. The low electrical resistance and high thermal conductivity of aluminium alloys inherently make resistance welding difficult. On the basis of the aforementioned governing equation, when the resistance of the work sheets are low, and the heat input to the system is dissipated quickly, the weld time must be short and the weld current very high to generate the required heat to form a weld. The weld nugget is formed because of shortened weld time and rapid cooling of aluminium, which can help solidification in less time. Proper electrode alignment and force distribution are mandatory along with electrode backup force for weld consistency and quality, as the weld is formed in relatively short periods in comparison to steel welds. Spinella et al. demonstrated force threshold that must be met to produce consistent welds. This force helps to break the oxide layer, permitting uniform distribution of the weld current through the cracks of the broken oxide layer. For such a scenario, the force must not only be at a certain level, but must also be uniformly distributed across the entire weld area. With the added complexity of the tenacious aluminium oxide layer at each of the interfaces in the weld area, resistance spot welding can become very erratic and hard to predict. The localized heating at the electrode work interface added with the rapid heating and cooling cycles of each weld can cause rapid electrode wear and the pitting phenomenon, which is noted only in aluminium resistance welding. The erosion process is initiated with pitting, which is triggered by the brittle fracture of local bonds that occur at the intermetallic phases. After the pitting, a secondary pitting process continues, The secondary pitting process has been put forward by Lum et al., who described the method as involving transfer of small amounts of molten copper from the electrode in the liquid state. This occurred as a result of intense heating and increased contact resistance at the location of existing pits. This leads to localized melting of the copper alloy welding electrode. These pits in the electrodes have as little as 20 welds. After significant number of small pits forming on the electrode surface, further welding brings the pits together forming a large central pit. This process is termed as cavitations. Subsequent to this step, the weld force and current are restricted to only a small ring on the outer periphery of the large pit. At this point, weld quality and consistency are extremely reduced. Lump et al. summarized electrode degradation of conventional copper alloy electrodes when welding AL5182 in the following four steps:

- Aluminum alloy pickup,
- Electrode alloying with aluminum,
- Electrode tip face pitting,
- Cavitations.

PRODUCTION OF ALUMINIUM DI OXIDE

Aluminum oxide is commonly denoted as alumina. It has strong ionic interatomic bonding, which are responsible for the desirable material characteristics. It can exist in several crystalline phases. However, these phases revert to the most stable hexagonal alpha phase at elevated temperatures. This phase is most important for structural applications.

The material is available from Accuratus.

Table 1: Properties of Aluminium

PROPERTIES	
Molecular Formula	Al ₂ O ₃
Molar mass	79.866 g/mol
Appearance	White solid
Odor	Odorless
Density	3.95 – 4.1 g/cm ³
Melting point	2072 °C
Boiling point	2977 °C
Solubility in water	Insoluble
Refractive index (n_D)	$n_o = 1.768 - 1.772$ $n_e = 1.760 - 1.763$
Thermal conductivity	30 W/m.k

NICKEL

Nickel is represented as **Ni**, with atomic number 28. It is a silvery-white lustrous metal with a slight golden tinge. Nickel is hard and ductile transition metal. Pure nickel has significant chemical properties that are displayed when nickel is powdered to maximize the exposed surface area on which reactions can occur. However, larger pieces are slow to react with air at ambient conditions, as a protective oxide layer is formed on the surface. Despite this, nickel is reactive with oxygen. This is the reason why native nickel is rarely found on Earth's surface. The metal is only found in the interiors of larger nickel–iron meteorites that were protected from oxidation during their time in space. On Earth, such native nickel is always found in combination with iron. Such an occurrence is a reminder of the elements' origin as major end products of supernova. The Earth's inner core is considered to be of iron–nickel mixture.

COATING TECHNIQUES

Vacuum Deposition and Vaporization

In the vacuum deposition process, elements, alloys or compounds are vaporized and deposited in a vacuum. Vaporization is achieved thermally at a pressure of less than 0.1 Pa (1 m Torr) and in vacuum levels of 10 to 0.1 MPa. The substrate temperature varies from ambient to 500°C. The saturation or equilibrium vapor pressure of a material is described as the vapor pressure of the material in equilibrium with the solid or liquid surface. For vacuum deposition, the deposition rate may be fairly good if the vaporization rate is substantially high. A useful deposition rate is obtained at a vapor pressure of 1.3 Pa (0.01 Torr).

Physical Vapor Deposition (PVD)

Physical vapor deposition (PVD) is a type of vacuum deposition. It includes all methods that deposit thin films by the condensation of a vaporized form of the material onto various surfaces (e.g., onto semiconductor wafers). Various physical processes are involved such as high temperature vacuum evaporation or plasma sputter bombardment. This is in variation to the chemical reaction method, which involves chemical interactions on the surface as in chemical vapor deposition.

Chemical Vapor Deposition (CVD) and Chemical Vapor Condensation (CVC)

CVD involves deposition of a solid on a heated surface by a chemical reaction that employs the vapor or gas phase. CVC reaction requires activation energy to proceed. This energy can be different sources. In thermal CVD, the reaction is activated by a high temperature above 900°C. A typical apparatus has a gas supply system, deposition chamber and an exhaust system. In plasma CVD, the reaction is activated by plasma at temperatures between 300 and 700°C. In laser CVD, pyrolysis occurs because of the laser thermal energy heating an absorbing substrate. In photo-laser CVD, the chemical reaction is induced by ultra violet radiation, which has adequate photon energy to chemically break the bonds in the reactant molecules. This is a photon-activated process, with deposition at room temperature.

Nano composite powders have been prepared by the CVD method. Sic/Si₃N composite powder was prepared using SiH₄, CH₄, WF₆ and H₂ as a source of gas at 1400°C. Chemical vapor condensation (CVC) is an alternative process developed in Germany in 1994. This process uses pyrolysis of vapors of metal organic precursors in a reduced pressure atmosphere.

D.C Plating

D.C plating deposits a coating by electrolysis. This coating helps to improve appearance, increases the resistance to corrosive agents and withstands abrasion. Various other desired properties or a combination of them might be obtained by this method.

However, for engineering applications of this plating method, the distribution of metal over the surface of the cathode needs to be regulated. The main fundamental principle of electroplating depends on the laws of electrolysis formulated by Faraday.

Pulse Plating

Currently, pulse plating is the more popular choice, as it overcomes the problems of DC plating. Pulse plating is defined as metal deposition by pulsed electrolysis (interrupted direct current to electroplate parts). Pulse plating deposits are smoother and fine-grained, as well as completely free of pinholes. This method also eliminates the variation in plating thickness. Additionally, plating speeds can be increased. Current efficiency is also reported as better, with low rates of raw material consumption. Pulse plating seems to be best for precious metal electrode position, because these industries can bear the cost of advanced equipment as the substantial savings in metal consumption and higher quality deposits compensate this. Furthermore, pulse plating has set control parameters. In the conventional direct current electrode position, there is only one parameter namely the current density, which can be varied. However, in pulse method, there are three important variables: pulse duration, pulse duty cycle and pulse current. However, this advantage can prove cumbersome when only one parameter needs to be chosen and optimized for a specific objective.

Basic Operating Principle of Pulse Rectifier

In Pulse mode technology, the direct current is chopped into square wave pulses of many thousands time per second. By fluctuating the number of pulses per second and the extent or width of the pulse, the output can be completely controlled. Alternating current enters the pulse rectifier from the mains supply. The alternating current on the secondary side of the transformer is converted to direct current with the help of a bridge rectifier. A filter circuit consisting of a choke and capacitor is used to smoothen the DC output. Finally, a DC supply with less than 5% ripples feeds the pulse circuit.

The DC power is chopped into square wave pulses with the DC output. The DC output is determined by the frequency of pulses and the width of the pulses. Pulse width modulation control circuits are used for this purpose. The pulse frequency and pulse width are regulated using softwares.

Process Principles

The pulse frequency and 'on' and 'off' times (duty cycle) are variables that can be set according to the requirements of an application. This operation is regulated using a programmable software.

The following two modes of operation are used:

- constant current and
- constant voltage mode.

The theory behind the pulse plating is simple (Chen, 1971). The film around the cathode is rich in metal ion and low in impurities. During 'on' time, the metal ions in the neighborhood of the cathode are depleted. At the end of this step, a layer rich in water molecules is formed. When the current is off, the metal ions from the bulk of the plating solution diffuses into the layer next to the cathode. The on–off cycles are repeated. During the 'off' time, gas bubbles and other impurities absorbed on the cathode get desorbed and removed.

SINGLE PULSE RECTIFIER

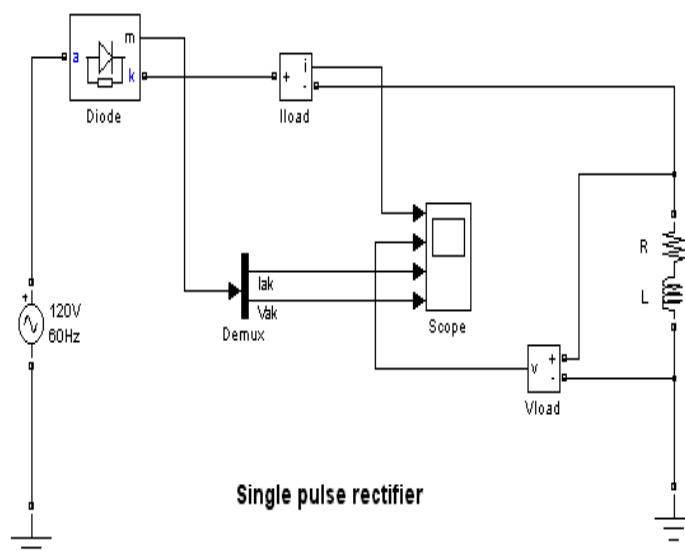


Figure 1: Single Pulse Rectifier

Table 1

Aluminum Alloy AL5182 Worked and Heat						
Treated						
Chemical composition						
Element	Si	Fe	Cu	Mn	Mg	Al
Wt%	0.08	0.19 0	0.05	0.32	4.71	Bal.

Composition of AL5182

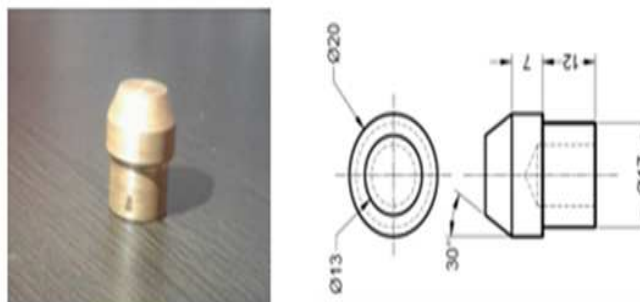


Figure 2

EXPERIMENTAL PROCEDURE

Welds were made on 1.5mm thick AA5182-H111 (Table 1) using a 170-kVA MFDC pedestal resistance spot welding machine. The surface was not cleaned before welding. All tests used Class 2 CuCrZr copper alloy electrodes. These electrodes had a modified tip geometry. Some electrodes used a TiC-MMC coating. This coating completely covered the weld face and also some parts of the surrounding electrode face.

Electrode Geometry

Huys Industries Ltd. Designed the electrodes used (Figure 1). These electrodes have a truncated cone E-nose style body with a slightly curved weld face with a predetermined diameter. The study used both coated (Al-Capp(TM)) and uncoated variations of this electrode. The coating was different from the TiCap(TM) coating used for resistance welding of steel alloys.

ANALYSIS REPORTS

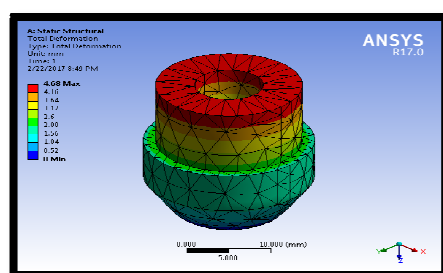


Figure 3: Deformation Analysis for Uncoated Electrode

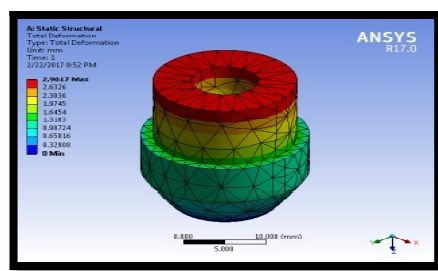


Figure 4: Deformation Analysis for Coated Electrode

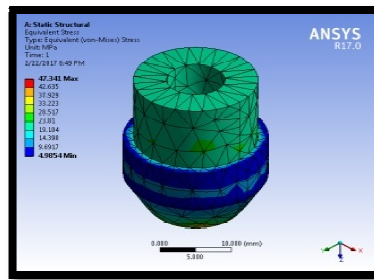


Figure 5: Analysis of Stress for the Uncoated Electrode

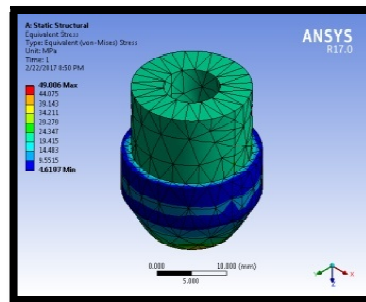


Figure 6: Analysis of Stress for the Coated Electrode

The analysis reported improved performance for uncoated electrode in comparison to the coated electrode (Al-CAPP™)

CONCLUSIONS

Al₂O₃-coated electrode has been demonstrated to be capable of forming larger welds than a traditional uncoated electrode. Simultaneously, the welding parameters help in producing a larger welding window, which is more suitable and robust for production. The resultant welds were considerably more rounder and consistent in nature when peeled and cross-sectioned in comparison to the uncoated electrode. This observation was because the Al₂O₃ electrode coating served as an additional interfacial layer providing additional electrical resistance and thermal insulation. The electrode life for a static weld current and force test was approximately double that of the uncoated electrode. In a production environment with escalating current, the coated electrode could constantly reach 5000 welds

REFERENCES

1. Spinella, D. J., Brockenbrough, J. R., Fridy, J. M., "Trends in Aluminum Resistance Spot Welding for the Auto Industry", AWS Welding Journal, Vol. 84 No. 1, Jan. 2005
2. Lum, I., Fukumoto, S., Biro, E., Boomer, D. R., Zhou, Y., "Electrode Pitting in Resistance Spot Welding of Aluminum Alloy 5182", Metallurgical and Materials Transactions A, Vol. 35A, Jan 2004, pp. 217-226.
3. Fukumoto, S., Lum, I., Biro, E., Boomer, D. R., Zhou, Y., "Effects of Electrode Degradation on Electrode Life in Resistance Spot Welding of Aluminum Alloy 5182", AWS Welding Journal, November 2003, pp. 307-S - 312-S.
4. S. Dong, Y. Zhou, "Effects of TiC Composite Coating on Electrode Degradation in Microresistance Welding of Nickel-Plated Steel", Metal. And Materials Trans. A., Vol. 34A, July 2003, pp. 1501-1511
5. Chan, K. R., Scotchmer, N., Zhao, J., Zhou, Y., "Weldability Improvement Using Coated Electrodes for RSW of HDG Steel", SAE World Congress Conference Proceedings, SAE International Detroit, 06

6. Ikeda, R., Yasuda, K., Hashiguchi, K., Okita, T., Yahaba, T., "Effect of Electrode Configuration on Electrode Life in Resistance Spot Welding of Galvannealed Steel and Aluminum Alloy For Car Body Sheets", IBEC 1995, *Advanced Technologies and Proceedings*, pp. 144-151
7. Xu, L., Khan, J. A., "Nugget Growth Model for Aluminum Alloys During Resistance Spot Welding", *AWS Welding Journal*, November 1999, pp. 367-S - 372-S.

